

The Effective Volatility of Motor Fuels

By

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Motor-Fuel Volatility¹ III—Effective Volatility under Driving Conditions^{2,3}

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IN CONSIDERING the vaporization, distribution, and combustion of fuel in carbureted internal-combustion engines, it is obvious that conditions never reach equilibrium in the intake manifold. For this reason attempts to make a direct comparison between the equilibrium volatility of a fuel as determined in the laboratory and engine acceleration as determined by actual engine-test data almost always fail.

Data reported by Brooks (2) based on actual engine tests with the intake manifold at 10° C. (50° F.) indicated that three fuels gave increasing acceleration in the inverse order of their A. S. T. M. distillation 50 per cent point volatility, while with the manifold at 32° C. (90° F.) the same fuels gave increasing acceleration in the direct order of their 50 per cent point volatility. To make interpretation still more difficult, Brooks stated that, although aviation gasoline gave better acceleration than the three fuels at a manifold temperature of 43° C. (109° F.), at the lowest temperature, 10° C. (14° F.), aviation gasoline gave the poorest performance of any of the four fuels, although showing a higher equilibrium volatility throughout the entire range.

These results indicate that any relationship between fuel

¹ The investigations reported in this series of papers have been carried out during the past four years in the Chemical Engineering Laboratory of the University of Michigan. Owing to the interdependence of various phases of the work, publication of the results has been delayed. More complete information than can be given in this series of papers will be found in *Bulletin 14* of the Department of Engineering Research of the University of Michigan, available in the near future.

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³ Part of a thesis submitted by J. E. Miller in partial fulfillment of the requirements for the degree of doctor of philosophy at the University of Michigan.

characteristics and engine performance must be based primarily upon actual engine-test data. Laboratory tests for volatility may be of great value in interpreting the engine-test data, but cannot be relied upon as a basis for determining the relationship between fuel volatility and engine performance.

As differences in motor-fuel volatility and engine performance are most evident during acceleration, the relationship between these two factors can be best determined by engine-acceleration tests under carefully controlled and constant conditions. When driving a car at constant speed, a steady state is reached in the intake manifold, so that all the fuel supplied by the carburetor is distributed more or less uniformly to the various cylinders almost regardless of the volatility characteristics of the fuel. During periods of acceleration, particularly with a cool motor or manifold, the amount of fuel delivered to the cylinders immediately after the throttle is suddenly opened is less than that supplied to the manifold by the carburetor.

If the fuel sprayed into air stream in the carburetor is not completely vaporized, some of the liquid particles settle out of the air stream and deposit on the walls of the manifold, where their progress from the carburetor to the cylinders is much slower than that of the air and vaporized fuel. When the throttle is suddenly opened, the increased air flow reaches the cylinders almost immediately, as does the fuel which is vaporized and carried in the air stream; but the liquid fuel flowing along the walls of the manifold does not reach the cylinders until some time later.

As a result of this partial precipitation of the fuel on the walls of the manifold, the mixture reaching the cylinders immediately after the throttle is opened contains less fuel than that mixture metered by the carburetor into the lower end of the manifold. When the air flow through the manifold is at a relatively high rate, part of the liquid fuel may reach the cylinders almost immediately after the throttle is opened in the form of a mist. But when the velocity of the mixture through the manifold is low, as when attempting to accelerate the motor from low engine speed, the air stream may not carry much suspended liquid and the mixture reaching the cylinders may be so lean in gasoline as to be beyond the explosive limits. Even under such conditions some liquid fuel is distributed by the liquid film on the wall of the manifold as well as by the fog or mist in the air stream, and may be burned in the cylinders almost as effectively as that fuel which is completely vaporized in the manifold.

In any attempt to determine the relationship between actual engine acceleration or performance and fuel characteristics, both the liquid reaching the cylinders and burned therein and the fuel which is vaporized in the manifold must be considered. The term "effective volatility," as used in this paper, takes these factors into consideration and can be employed as a direct indication of motor performance.

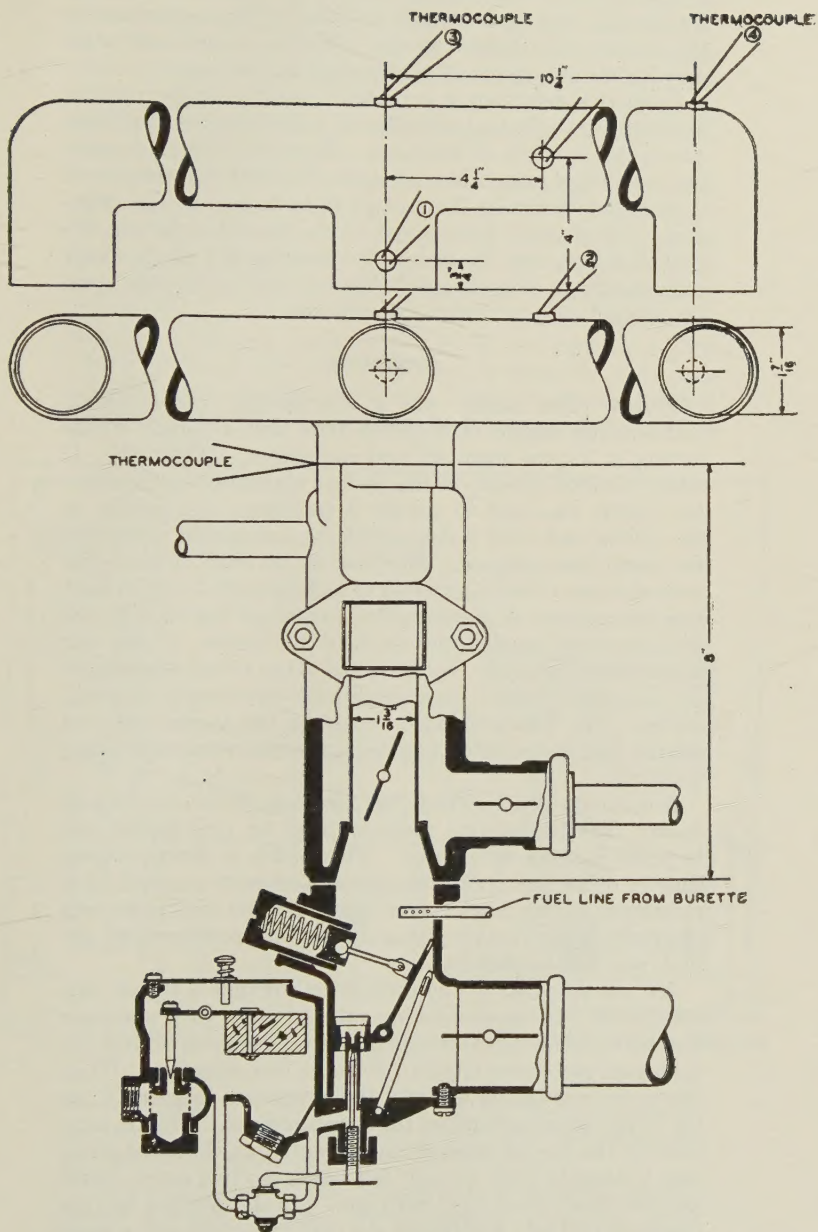


Figure 1—Cross-Section of Carburetor and Manifold Used in Acceleration Tests for Determination of Effective Volatility

Effective Volatility

The effective volatility of a fuel is the quotient obtained by dividing the air-fuel ratio supplied at the carburetor by the air-fuel ratio burned in the cylinders, immediately after opening the throttle in an acceleration engine test.

From this definition it is evident that the problem of determining the effective volatility of a fuel resolves itself into two simple but difficult problems. The first is that of measuring the air-fuel ratio delivered to the manifold, and the second is that of determining the air-fuel ratio burned in the cylinders. The former is measured by the special apparatus described below, and the latter by operating the motor under such conditions that the acceleration is dependent only upon the air-fuel ratio burned in the cylinders.

Apparatus

MOTOR—The motor was a six-cylinder, valve-in-head, water-cooled engine of $3\frac{1}{2}$ -inch bore and $4\frac{3}{4}$ -inch stroke having a T-type manifold and carburetor. (Figure 1) It was connected directly to the electric absorption dynamometer, which was used to supply a resistance comparable to the rolling and wind resistance of the automobile for which the motor was designed. Mounted on the shaft of the dynamometer was a steel inertia disk of such dimensions and weight that its moment of inertia added to that of the rotor of the dynamometer equaled the moment of inertia of the car when in high gear (4). By these means the actual driving load on the motor under road conditions was closely approximated. The disk and rotor furnished the inertia and the electric load represented approximately the wind and rolling resistance.

APPARATUS FOR CONTROL OF AIR-FUEL RATIO—It is well known that the air-fuel ratio supplied by commercial carburetors changes with speed. This makes it almost impossible to determine accurately the air-fuel ratio supplied by a carburetor during acceleration tests. Special equipment was therefore devised for supplying a constant predetermined air-fuel ratio during each test.

Air was supplied to the carburetor through a 2-inch pipe fitted with two quick-opening gate valves in such a manner that air could be taken directly from the laboratory or from the calibrated gasometer of about 50 cubic feet capacity. When the motor was taking air from the gasometer (Figure 2), the fall of the upper tank raised the counterweight. This, in turn, allowed the air-fuel ratio drum to rotate in a clockwise direction, letting the steel plunger fall inside the fuel buret, which had previously been filled with fuel. As the plunger fell, the displaced fuel was supplied to the carburetor through a small auxiliary jet placed about an inch above the regular jet in the carburetor.

The air-fuel control drum was made of twelve concentric pulleys of different diameters. The rate at which fuel was

supplied to the carburetor with any two of these pulleys in use varied directly as the rate at which air was used from the tank. The air-fuel ratio, therefore, remained constant regardless of the speed of the motor. Different air-fuel ratios were obtained by changing to smaller or larger pulleys on the drum. This equipment gave a precision in predetermining and controlling the air-fuel ratio absolutely unattainable with any commercial carburetor.

A vent line from the buret to the gasometer was found necessary to equalize the pressure and allow proper functioning of the buret. The seal at the top of the buret, to prevent air leakage, was constructed in the same manner as those described in Part I (3). Two small cocks, inserted between the jets and the bowl of the commercial carburetor supplied as factory equipment, allowed the operator to cut off all the fuel in the bowl from the jets when the motor was being run from fuel in the buret. Thus in a few seconds the operator could shift the fuel feed from the carburetor bowl to

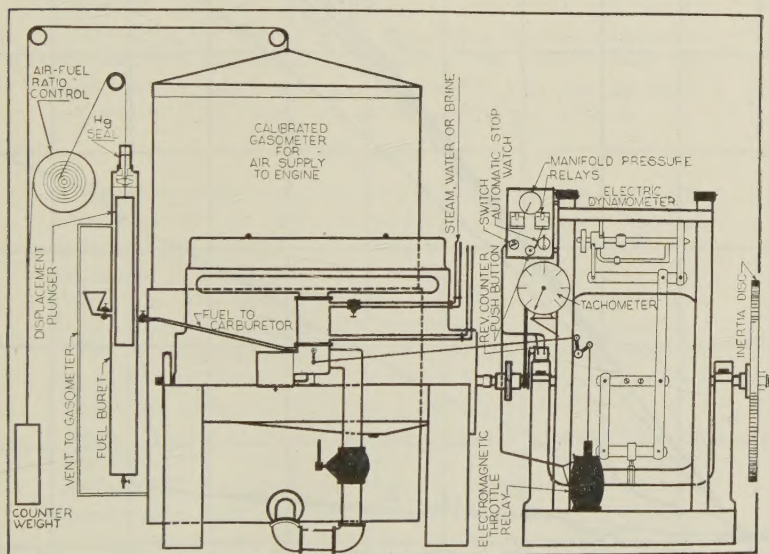


Figure 2—Apparatus Used in Making Acceleration Tests to Determine Effective Volatility

the fuel buret, and the air supply from the laboratory to the gasometer, by merely shifting the two cocks in the carburetor and the two quick-opening valves in the air line.

The temperature of the mixture in the manifold was recorded by chromel-copel thermocouples, extending about $\frac{1}{2}$ inch into the gas stream. These were located at four places on the manifold—one just above the heater, one on the horizontal arm, and two about an inch each from the ports where the mixture enters the block to the two end cylinders and to the middle cylinders. (Figure 1) A thermo-

couple was also placed in the wall of the manifold $\frac{1}{2}$ inch above the heater.

Thermometers were placed in the lubricating-oil stream to the bearings, in the cooling water to and from the engine block, and in the air pipe leading to the carburetor. The cooling water was circulated in a closed system through a water-cooled radiator and the motor block. By adjusting the tap-water supply to the radiator the operator could control the temperature of the block.

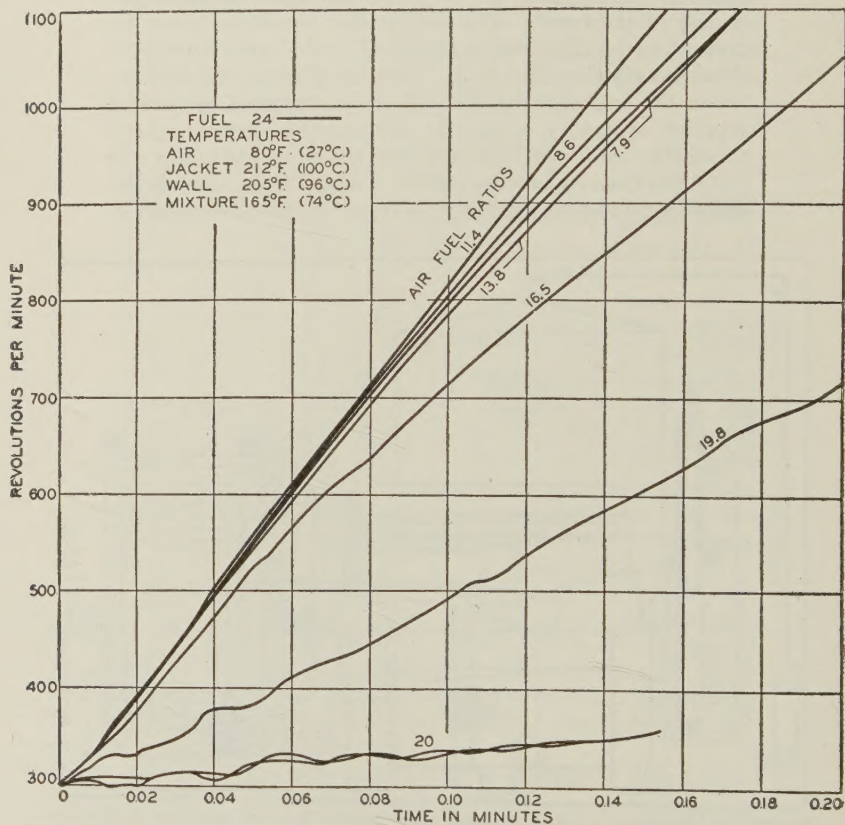


Figure 3—Acceleration Curves for Fuel 24 under Conditions Such that Practically All of the Fuel Supplied by the Carburetor Reached the Cylinders Immediately after the Throttle Was Opened

A manometer recorded the pressure of the air in the gasometer. This pressure was adjusted by the counterweights to give a positive pressure in the gasometer of 5 to 6 cm. of water. This pressure seemed to counterbalance the friction of the pulleys on the gasometer, so that the tank responded to the opening of the throttle instantly without any noticeable surging.

OPERATING CONTROL—In order to minimize human error,

the actual acceleration tests were started and stopped by a number of relays connected in series and operated by a single contact. Making contact by the push button on the panel closed a 6-volt battery circuit through a connection on one of the tappets of the motor and the left-hand relay. Closing this control relay sent a 220-volt d. c. through the locking relay on the right of the panel which automatically started the stop watch and energized two electromagnetic relays, one of which opened the throttle and the other started the motion-picture camera at the same instant. By this means a motion-picture record of the tachometer, starting at the same instant that the throttle was opened and the stop watch started, was automatically obtained for each acceleration.

The switch on the control panel was then turned to the off position. A contact made through the push button when the engine had accelerated to the desired r. p. m. energized the 6-volt relay, and broke the circuit through the 220-volt locking relay, automatically stopping the stop watch and camera and closing the throttle. By this means accurate data could be recorded concerning the action of the motor during the acceleration period with the operator free to give his entire attention to the proper control of operating conditions.

Procedure

In order to get the motor to a steady state, the motor was "warmed up" for 20 to 30 minutes by continuous running, followed by a series of accelerations using the carburetor at intervals of 3 minutes, for a period of 2 to 3 hours. This work was done with the carburetor adjusted to the leanest mixture or highest air-fuel ratio giving maximum acceleration.

These preliminary runs were continued until the temperature and state of dilution of the oil and the temperature of the water and of the manifold heater remained constant for some time. Several acceleration tests were then made with one fuel using the buret-gasometer feed at one air-fuel ratio to determine if conditions were sufficiently constant so that check acceleration tests could be made. When the time required to accelerate from 300 to 1100 r. p. m. for succeeding runs checked within 0.001 or 0.002, test data were taken.

TESTS—An acceleration was run from 300 to 1100 r. p. m. using the carburetor bowl in the ordinary manner to supply fuel and air to the manifold. Immediately after the completion of this test the air and gasoline valves were shifted so as to obtain the air supply from the gasometer and the fuel supply from the buret. The motor was then idled at 300 r. p. m. until 3 minutes had elapsed since the beginning of the preceding acceleration. An acceleration test was then made in the manner described above, after which the motor was again idled at 300 r. p. m. using the carburetor to supply air and fuel in the standard manner. One minute before each acceleration on the buret feed, readings were taken on all

thermometers and thermocouples. This schedule was maintained throughout the day for different fuels and with different air-fuel ratios.

There were two reasons for alternating the buret and the carburetor. It gave the operator an opportunity every 6 minutes to check the motor performance under identical conditions. Since temperature and fuel conditions in the manifold and motor change slightly with the different air-fuel ratios run between the carburetor accelerations, the motor conditions could not be kept exactly constant, but this procedure practically eliminated the effect of one air-fuel ratio on the acceleration curve of the succeeding run. Two carburetor runs between each buret run gave slightly more consistent results. However, the improvement was insufficient to warrant the extra time required.

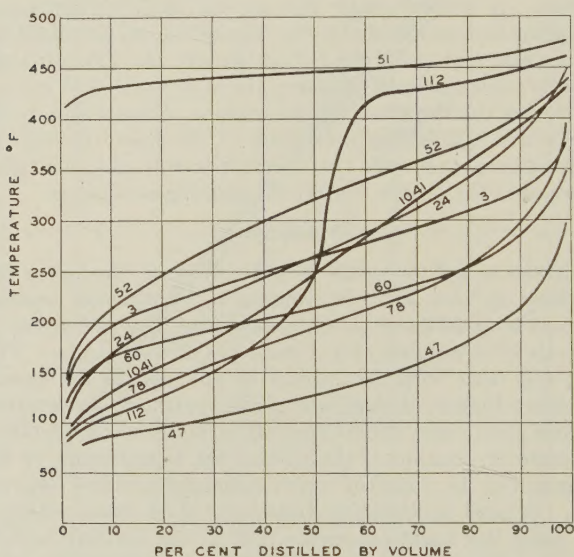


Figure 4—A. S. T. M. Distillation Curves of Fuels Used in Acceleration Tests for Determining Effective Volatility

The time interval of 3 minutes between accelerations was found to give consistent results and represented a convenient interval. Brooks (2) found that, on a similar motor, accelerations run every 2 to 4 minutes gave better checks than those at either shorter or longer intervals.

In running accelerations on a fuel of unknown effective volatility, several trial tests were made to determine the ratio at which it would give almost perfect acceleration. Then the accelerations were run on successively leaner mixture ratios until no acceleration could be obtained under the conditions of test. In this way the complete range was covered on most of the fuels investigated.

CALIBRATION OF MOTOR—Since all factors other than fuel

characteristics and air-fuel ratio were maintained as constant as possible in each series of tests, changes in the acceleration obtained within each series were due to changes in the air-fuel ratio burned in the cylinders. The acceleration was determined as a function of the air-fuel ratio burned in the cylinders for each series of tests and for each day's run by using a standard fuel which was completely effectively vaporized under the conditions of the test. When a fuel is com-

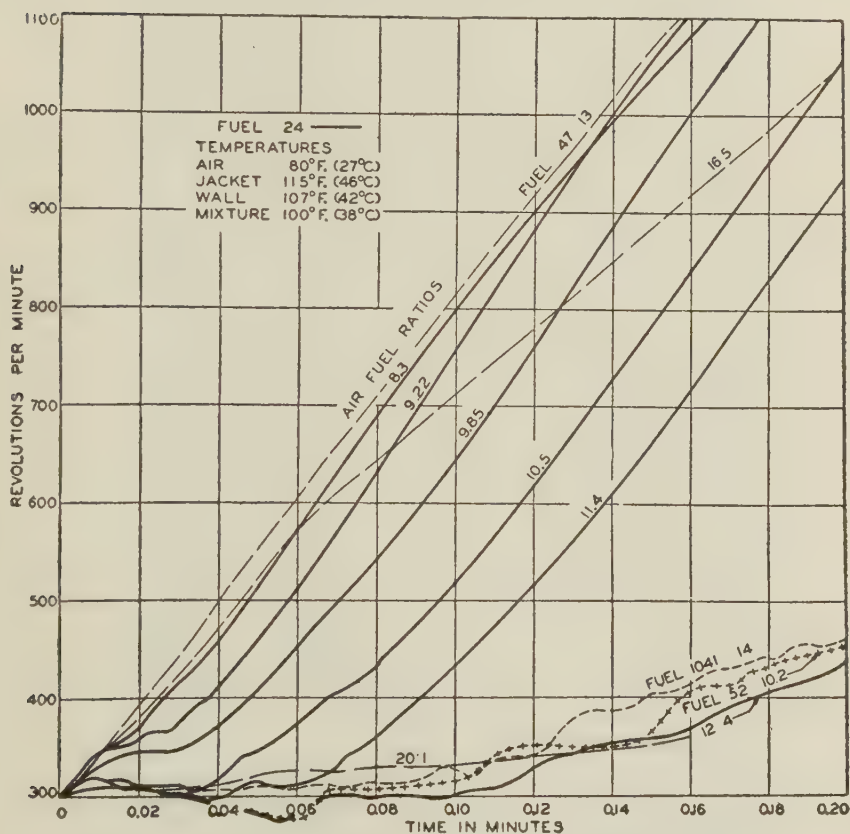


Figure 5—Acceleration Curves for Fuel 24 at Low Manifold Temperatures

Dashed lines represent fuel 47 which is practically completely effectively vaporized under these conditions. Curves for fuels 1041 and 52 are included for comparison.

pletely effectively vaporized, the air-fuel ratio burned in the cylinders is by definition substantially the same as that metered to the manifold. A characteristic set of these curves is shown in Figure 3.

In order to be sure that the standard fuel was completely effectively vaporized, more volatile fuels were run at the same manifold temperature. When the acceleration from these fuels were no better than those of the standard fuel, the standard fuel was considered to be completely effectively

vaporized. This conclusion was verified by running accelerations on the standard fuel at higher and lower manifold jacket temperatures.

FUELS USED—The fuels used in this investigation (Figure 4) cover the entire range of commercial gasolines.

Measure of Acceleration

For comparing results of acceleration tests a quantitative measure of acceleration is necessary. The acceleration was taken as the increase in r. p. m. in the time interval between 0.1 and 0.06 minute after the throttle was opened. On the curve for a 19.8:1 ratio in Figure 3, the speed at 0.06 minute is 408 r. p. m., that at 0.01 minute is 310 r. p. m., and the acceleration is recorded as 98 r. p. m.

There were four reasons for choosing the time interval 0.01 to 0.06 minute. In the first place, in an investigation into fuel characteristics an average or integrated value as observed over a finite time interval is preferred to an instantaneous acceleration which varies within wide limits during a single test and is therefore more suited for studying engine variables than fuels which do not change during a test.

Secondly, the acceleration is about the same for all except high air-fuel ratios during the first 0.005 to 0.01 minute, and is therefore not a function of air-fuel ratio or fuel volatility during this time interval. This may be due to the inertia effects in the manifold or in the air valve of the carburetor, subsequent to the opening of the throttle. Therefore the acceleration before 0.01 minute should be neglected, as it depends largely upon constant manifold conditions and not upon fuel volatility.

Thirdly, when using lean mixtures, a break in the speed-time curve is frequently observed after about 0.06 to 0.1 minute, as shown in Figure 5. Upon investigation it was found that the mixture temperature decreased during an acceleration as shown in Figure 6. This decreases the effective volatility of the fuel to such an extent that the loss in acceleration is clearly evident in the speed-time curve. For this reason the acceleration following about 0.06 to 0.1 minute should not be included in determining the effective volatility as existing under the initial conditions.

At temperatures considerably below that of complete vaporization the unvaporized portion of the fuel builds up a film on the manifold walls. The sudden opening of the throttle causes an increase in pressure and further condensation of fuel on the manifold wall. This liquid fuel flows along the manifold, but at a velocity much less than that of the air stream. When starting an acceleration at 300 r. p. m. from 0.06 to 0.08 minute is required for this additional liquid to reach the cylinders.

This action is evident in Figure 7. During the first 0.06 or 0.08 minute, which seems to represent the time lag in distribution of the liquid flowing along the manifold wall, the

acceleration is largely determined by the air-fuel ratio, since the volatility of the fuel is approximately the same for different air-fuel ratios if the manifold is kept at the same temperature. But after 0.08 to 0.10 minute the accelerations of the different mixtures from 9.2 to 11.4 are almost identical. An air-fuel ratio of 8.3 contains so much excess fuel that it cannot be burned efficiently and a loss of power results, as is shown by the decreasing slope of the acceleration curve beginning about 0.08 minute after the throttle was opened. The 12.4 mixture did not develop sufficient velocity to distribute the liquid satisfactorily, or possibly the engine temperature was so low that the last 10 to 15 per cent of the fuel did not burn even if distributed.

These data indicate clearly that after about 0.06 minute (4 seconds) conditions in the manifold reach a steady state in which the liquid fuel is distributed to the cylinders at about the same rate that it is deposited on the walls of the manifold, and approximately the same air-fuel ratio is then delivered to the cylinders as is supplied by the carburetor to the manifold.

In Figure 7 the speed-time curves of a fuel completely effectively vaporized at that temperature are plotted as dashed lines for 13 and 16.5 air-fuel ratios. The 8.3 ratio curve for fuel 24 parallels that of the 16.5 curve of fuel 47 from 0.01 to 0.06 minute, indicating the same air-fuel ratio burned in the cylinders, or an effective volatility of fuel 24 under these conditions of 8.1/16.5 or 49 per cent. At 0.06 minute these curves cross owing to conditions not attributable to fuel characteristics.

For these reasons the acceleration was taken as the increase in r. p. m. during the time interval 0.01 to 0.06 minute. This increase will be indicated by "acceleration" in the succeeding paragraph.

Experimental Results

All the acceleration data recorded by the camera and stop watch were plotted giving speed-time curves similar to those in Figures 3, 5, and 7.

The acceleration values, Δ r. p. m. from 0.01 to 0.06 minute, were plotted as a function of air-fuel ratio supplied as indicated in Figure 8.³ In this figure the two uppermost curves are standard curves indicating the acceleration as a function of the air-fuel ratio burned in the cylinders. These standard curves can be used to determine the air-fuel ratio burned in the cylinders in the case of those fuels not completely effectively vaporized. For example, fuel 1041, when supplied in an air-fuel of 10:1 at the carburetor and at a manifold jacket temperature of 103° F., gave an acceleration of 109 Δ r. p. m. This is identically the same acceleration obtained

³ In this paper only a few of the experimental data are presented. A complete report will be found in *Bulletin 14* of the Department of Engineering Research, University of Michigan.

when supplying the fuel which was completely effectively vaporized in an air-fuel ratio of 18.3:1. This comparison indicates that when fuel 1041 is supplied in an air-fuel ratio of 10:1 at 103° F. the mixture actually burned in the cylinders during the initial stages of acceleration is equivalent to an air-fuel ratio of 18.3:1, or that 10/18.3 or 54.7 per cent of the fuel supplied at the carburetor is actually carried to the cylinders and burned therein. Thus, the effective volatility may be readily computed by dividing the air-fuel ratio supplied by the air-fuel ratio of the standard giving the same acceleration, in the manner described.

The effective volatilities computed in this manner were tabulated and plotted as shown in Figure 9 as a function of the mixture temperature as recorded by thermocouple 1 inserted in the manifold near the center cylinders. (Figure 1)

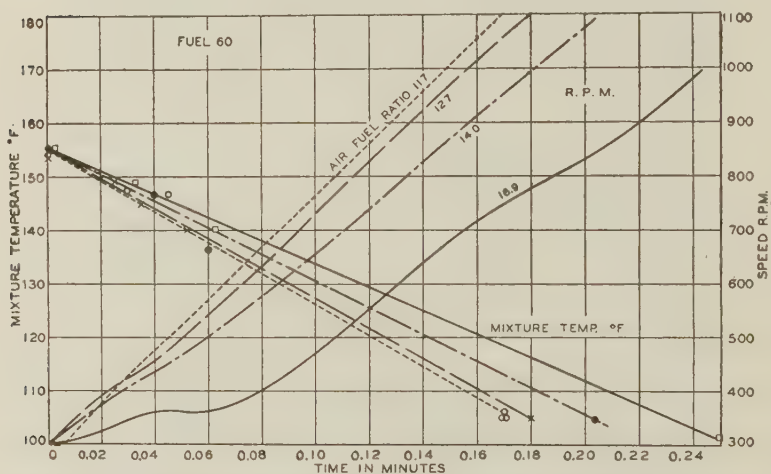


Figure 6—Mixture Temperature Plotted as a Function of Time after Throttle Is Suddenly Opened for Different Air-Fuel Ratios
Acceleration curves are also given for comparison.

MIXTURE-TEMPERATURE—At first it might appear that any one of the temperatures of the mixture or of the manifold wall might be used in determining effective volatility. The wall temperature was not used because it is only one factor determining mixture temperature. Changes in air temperature will affect mixture temperature and volatility even though the manifold wall temperature may remain constant. Effective volatility is concerned not so much with the relative amount of fuel distributed to the cylinders as with the relative amount of fuel actually burned in the cylinders. For this reason it is desirable to measure the temperature of the mixture at some point which gives consistent readings throughout the tests and also indicates the condition of the mixture entering the cylinders.

From these considerations it seemed that the temperature of the mixture should be taken at a point rather near the

cylinder block, as by thermocouple 1 or 4. (Figure 1) These temperatures are controlled largely by the air and manifold temperatures, but are also somewhat dependent upon the temperature of the block. This is desirable, as the block temperature is an important factor in determining the effective volatility of fuels.

The experimental data include mixture temperatures at four places in the manifold as indicated in Figure 1. Before deciding which temperature should be used, these data were

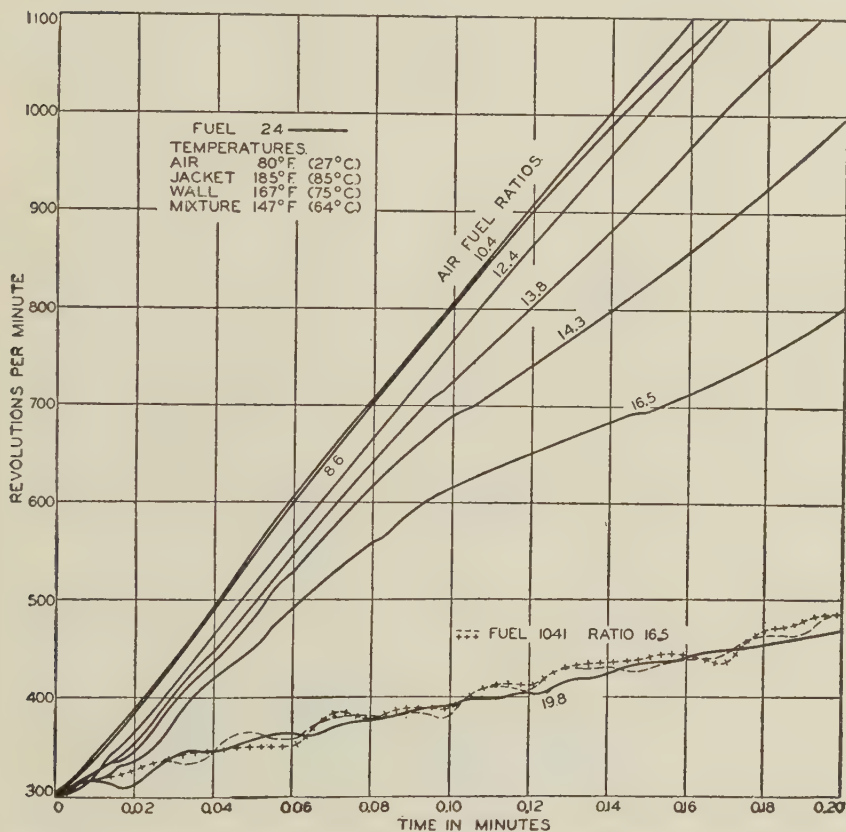


Figure 7—Acceleration Curves for Fuel 24 at Temperatures Lower than for Runs in Figure 3
All fuel supplied by carburetor does not reach cylinders immediately after opening of throttle.

carefully considered to determine the apparent relationship between effective volatility and the different temperatures. Although there was little difference between the temperatures recorded by the four thermocouples placed in the manifold above the heater, those recorded by couple 1 follow the changes in block temperature more closely than do the others.

When the accelerations were plotted for a definite manifold jacket temperature but for different block temperatures,

the effective volatilities were found to be dependent upon the block temperature as well as upon the manifold and air temperatures. The temperatures recorded by couples 2, 3, and 4 show no change, within the experimental error of about $\pm 2^\circ \text{F.}$, with changing block temperature. But the temperature recorded by couple 1 dropped about 5° to 7°F. when the block temperature was changed from 154° to 114°F. This difference quantitatively accounts for the change in effective volatility.

By means of other similar comparisons the temperature of the mixture as recorded by couple 1 was found to indicate the effective volatility of the fuel for different manifold, mixture, and block temperatures. For this reason all effec-

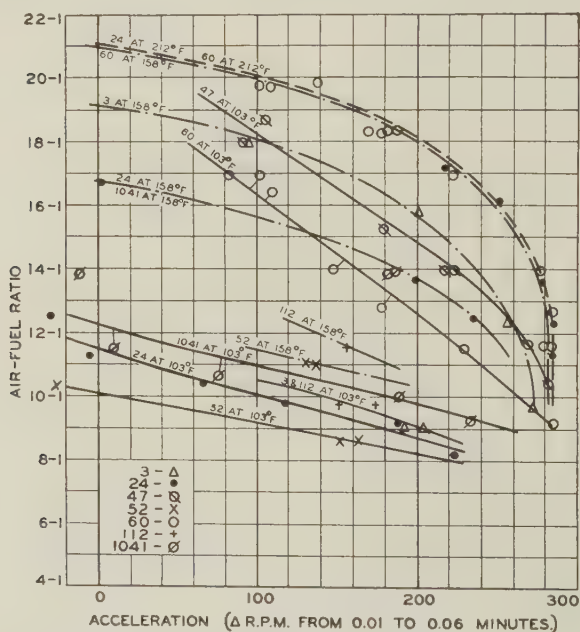


Figure 8—Acceleration Plotted as a Function of Air-Fuel Ratio Supplied at Carburetor

tive volatilities are reported in terms of this mixture temperature.

In Figure 8 all data are plotted in terms of manifold jacket temperature, because this temperature could be carefully controlled and the proper mixture temperature could not be determined until the above comparison had been made. In determining the effective volatility, however, the mixture temperature as recorded by thermocouple 1 is to be used and not the manifold jacket temperature, for reasons already discussed.

The data clearly show that the mixture temperature is dependent, not only upon the air and manifold temperatures,

but also upon the amount of fuel vaporized, which varies both for the different fuels and also for different mixture ratios with the same fuel. For this reason the initial mixture temperature was plotted as a function of the air-fuel ratio for various manifold jacket temperatures. The temperatures of the mixtures as read from these curves were used in plotting the points in Figure 9 for each air-fuel ratio.

Smooth curves (solid lines) were then drawn through the points and extrapolated when necessary to obtain the temperature of complete (100 per cent) effective volatility. In all cases the effective volatility curve becomes almost vertical below 50 to 70 per cent volatility.

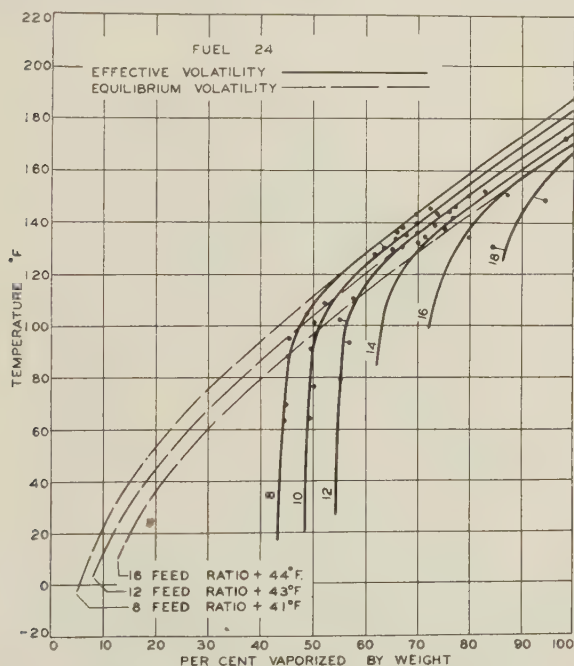


Figure 9—Effective Volatility and Equilibrium Volatility Plotted as a Function of Mixture Temperature for Air-Fuel Ratios

Limits of Accuracy

The air-fuel ratio supplied to the manifold by the gasometer and fuel buret was determined with an accuracy greater than that with which the acceleration or mixture temperatures could be measured. For this reason only the latter need be considered in determining the probable accuracy of the determinations.

The tachometer film records could be read to within ± 3 r. p. m., which would make a difference of from 1 to 2 per cent in accelerations of 150 to 250 Δ r. p. m. and 2 to 4 per cent for accelerations below 150 Δ r. p. m.

The mixture temperatures had to be taken rather rapidly and probably are accurate only within $\pm 2^\circ$ F., although they were all taken at the same point in the cycle of operation. In different tests with the same fuel and mixture-ratio the mixture temperatures agree within this limit. This might introduce an error of 2 per cent, or possibly 3 per cent in effective volatility.

If all errors combine in the same direction, the individual experimental results should still be accurate to within 8 per cent in effective volatility. The probable error in individual determinations is about ± 6 per cent. The final results based upon a large number of experimental data are probably accurate within about ± 2 per cent, as indicated in Figures 12 to 15.

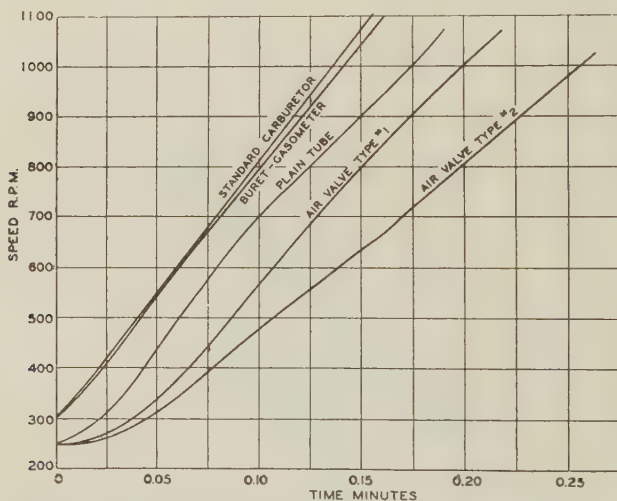


Figure 10—Comparison of Acceleration Curves Obtained with the Standard Carburetor and Buret-Gasometer Feeding Systems on Motor with Those Obtained with Different Carburetors on a Similar Motor by Eisinger

The method first considered for computing the effective volatility of fuels was that of comparing air-fuel ratios of practically identical acceleration curves for two different fuels, one of which was completely volatile under the conditions of test. Although this plan was abandoned because of the difficulty in obtaining curves which exactly coincided, in those cases where it could be applied, as in Figure 7, the results are approximately the same as those computed from plots such as Figure 8 as given in Figure 9.

The relative effective volatilities for the fuels whose acceleration curves do coincide are shown in Table I. In this table the fuels and ratios listed in the same line developed speed-time curves that are practically identical from the beginning to end. The relative effective volatilities as shown in column 10 were calculated from the two effective volatilities for the fuels

as determined from plots such as Figure 8 and listed in columns 5 and 9. Those in column 11 were calculated by dividing the corresponding air-fuel ratios of coinciding acceleration curves. The agreement is very close in all cases, indicating that the acceleration over the 0.1 to 0.06 minute interval does give the true effective volatility of the fuel, which is of significance throughout the entire acceleration period.

In the last comparisons shown in Table I, the curve for 47 at a 15.5 air-fuel ratio lies between the curves for fuel 24 at 10.6 and 11.5 mixture ratios. The relative effective volatilities of the two fuels as determined from their effective volatilities were 69 and 72 per cent. The relative effective volatilities as determined by dividing the corresponding air-fuel ratios were 68.4 and 73 per cent, respectively.

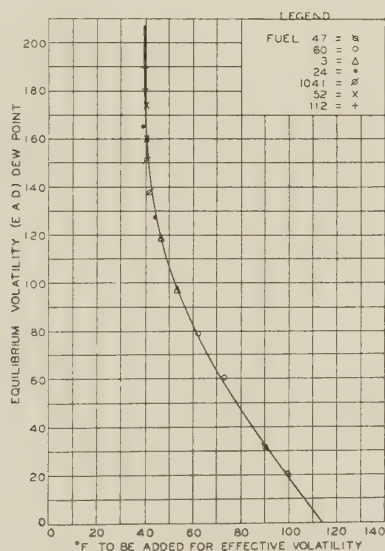


Figure 11—Number of Degrees Fahrenheit to Be Added to Dew Point to Determine Temperature at Which Fuel Is Completely Effectively Vaporized under Actual Driving Conditions

The data in Table I also indicate the probable accuracy of the determinations of effective volatility. The relative effective volatilities agree well within 2 per cent in practically all cases.

Similarity between Buret-Gasometer and Carburetor Methods of Metering

The possibility of the positive displacement method of metering fuel having a pronounced influence on the accelerations was carefully considered. In order to reduce such effect to the minimum, the fuel jet was placed in the commercial carburetor supplied as factory equipment so that the air stream received the same throttling as when the standard

Table I.—Relative Effective Volatilities by Δ r. p. m. and Coinciding Acceleration Curves

FIGURE	FUEL	AIR-FUEL RATIO	MANIFOLD JACKET	EFFECTIVE VOLATILITY	FUEL	AIR-FUEL RATIO	MANIFOLD JACKET	EFFECTIVE VOLATILITY	RELATIVE EFFECTIVE VOLATILITY As in Fig. 8	RELATIVE EFFECTIVE VOLATILITY As in Fig. 8
1	2	3	4	5	6	7	8	9	10	11
10, 5	24	19.8	190	96	1041	16.5	190	81	84.5	83.0
9, 7	1041	14	111	66.5	24	12.4	111	59.5	89.5	88.5
9, 7	24	12.4	111	59.5	52	10.2	111	48	81.5	82.2
9, 7	1041	14	111	66.5	52	10.2	111	48	72.2	73.0
9	112	9.87	111	52	52	8.8	112	47.5	91.3	89.2
9	47	15.3	103	81	60	14.0	113	73	90.2	91.5
8	60	21.8	212	100	60	16.65	95	75	75	76.3
8	60	16.65	212	100	60	8.58	54	51	51	51.5
8	60	16.5	95	75	24	11.5	95	52	69.5	69.6
8	47	15.5	54	74	24	10.6	54	51	69	68.4
					24	11.5	54	53	72	73

carburetor was in use. Comparison of the maximum acceleration obtained with the buret-gasometer and standard carburetor in Figure 10 indicates a barely noticeable difference. This is far less than that shown in the lower curves, representing the maximum accelerations obtained with three different carburetors on a similar motor as reported by Eisinger (4).

Relation between Effective and Equilibrium Volatility

The effective-volatility curves (Figure 9) show little in common with the equilibrium-volatility curves of a similar fuel (fuel 13) as reported in Part I (3). Reasoning that the equilibrium is not reached in the manifold of a motor because of the short time interval allowed for vaporization therein, it seemed that the temperature of complete effective volatility would be higher than the dew point or temperature of complete volatility under equilibrium conditions, and might be estimated by adding some number, yet to be determined, to the corresponding dew point. In order to make this comparison and to determine a relationship by which the effective volatility might be estimated from the equilibrium volatility, in Figure 9 the temperatures of each equilibrium volatility curve as computed in Part I from the equilibrium-vaporization curve (Figure 4 of Part II) have been increased throughout by a constant amount so that as plotted the dew point coincides with the corresponding temperature of complete (100 per cent) effective volatility. It was found that a different number had to be added to each dew point. These numbers added to the dew point to obtain the temperature of complete effective volatility are plotted as a function of the dew point in Figure 11. It is clear that a greater number must be added to low dew points, as reactions take place more rapidly and the difference between actual and equilibrium conditions in the manifold will be less at high temperatures. Comparison of the modified equilibrium and effective volatility curves as plotted in Figure 9 indicates that the effective and modified equilibrium volatility curves coincide throughout only the upper range. For less than 50 to 70 per cent vaporized the effective-volatility curve falls away from the modified equilibrium curve, indicating a relatively greater effective volatility.

In Figures 12 to 15 this "liquid distribution," expressed as a percentage of the total fuel to be added to the equilibrium volatility, is plotted as a function of the corresponding equilibrium temperature. At lower temperatures the liquid distribution becomes larger. This is probably due to the combined effect of the greater density of vapor being able to carry more mist, and the greater viscosity of the fuel, which allows a thicker film to be maintained on the walls of the manifold during the idling period previous to opening the throttle for an acceleration. The liquid fuel distributed to the cylinders by means of a film flowing along the manifold

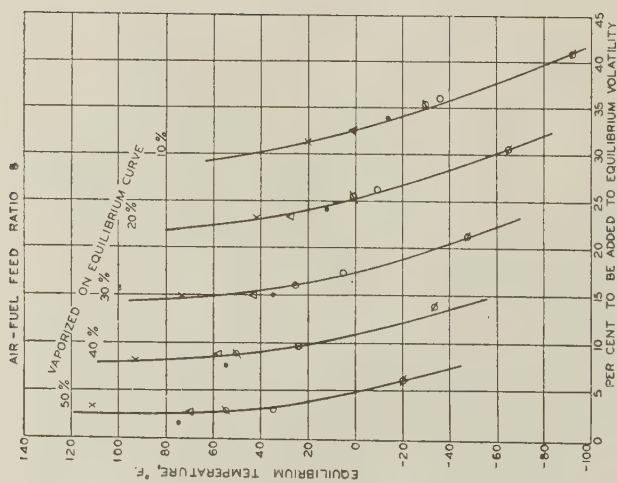


Figure 12

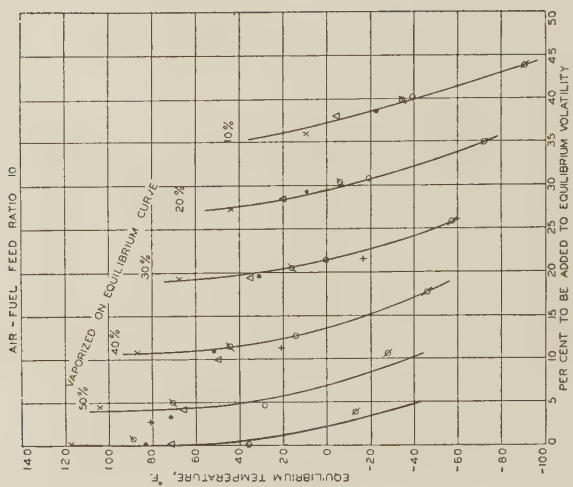


Figure 13

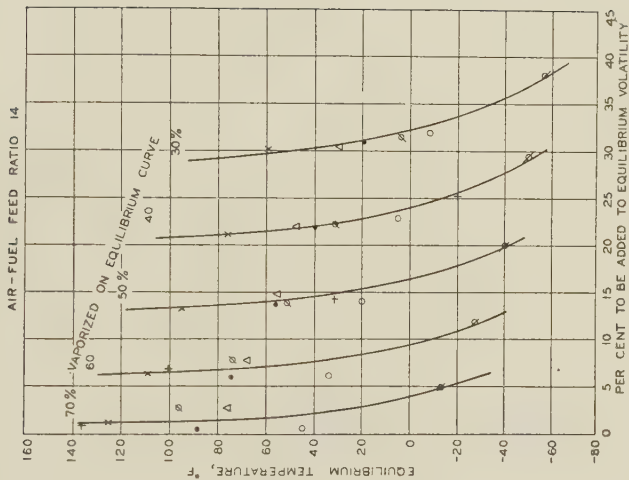


Figure 14

Per Cent to Be Added to Equilibrium Volatility Curves to Obtain Effective Volatility Curve Plotted as a Function of Equilibrium Temperature for Indicated Percentage Vaporized on Equilibrium Volatility Curve for Indicated Air-Fuel Feed Ratios

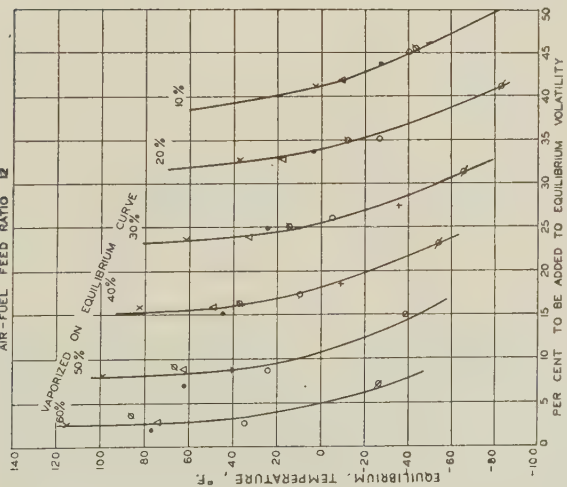


Figure 15

walls during the idling period is also similarly distributed during the first 4 seconds (0.06 minute) after the throttle is opened or until the liquid fuel forming the new film can reach the cylinders.

By use of the relationships given in Figures 11 and 12 to 15 the effective volatility of any motor fuel may be readily calculated from the equilibrium volatility or air distillation of the fuel. The equilibrium volatility is computed from the equilibrium vaporization curve by the method previously described (3). The "liquid carry," as indicated in Figures 12 to 15, is added to the corresponding points on the equilibrium-volatility curves to obtain the modified equilibrium volatility of the fuel as determined for this engine. The temperature difference, given in Figure 11 as a function of the dew point, is then added to each temperature of the modified equilibrium curve to obtain the effective volatility.

Because this method is rather long and indirect, it would be far more convenient if the effective volatility were interpreted in terms of engine performance and estimated directly from the A. S. T. M. distillation, even with some loss in accuracy.

Interpretation of Effective Volatility and A. S. T. M. Distillation in Terms of Engine Performance

If the motor is to be driven without use of the choke, the effective volatility of the fuel must be sufficient to deliver at least an explosive mixture to the cylinders under all conditions of operation. Assuming that the carburetor is adjusted to deliver a 12:1 air-fuel ratio, and that a 20:1 air-fuel ratio is the leanest mixture that can be exploded in the engine, it is evident that the effective volatility of the fuel must be not less than 60 per cent if the motor is to be kept running. From the data reported above it is seen that the effective volatility in a 12:1 mixture is about 60 per cent when apparently 58 per cent of the fuel is actually vaporized. Since the 58 per cent point on the equilibrium volatility curve may be related approximately to the 58 per cent point on the A. S. T. M. distillation (3), the latter would seem to be important in indicating the minimum temperature of the mixture at which the car could be operated without use of the choke, provided the carburetor supplies an air-fuel ratio of about 12:1.

Most modern cars are equipped with carburetors supplied with accelerating devices which inject an additional charge of fuel into the manifold whenever the throttle is suddenly opened. The effect of these accelerating charges is to deliver a mixture ratio of approximately 8:1 during the early stages of the acceleration when the carburetor is adjusted to supply a 12:1 air-fuel ratio under steady conditions. With an air-fuel ratio of 8:1, 55 per cent equilibrium volatility appears to correspond directly to 55 per cent effective volatility, or an air-fuel ratio of about 14.5 supplied to the cylinders. A mix-

ture ratio of 14.5 is sufficiently rich to give satisfactory acceleration. But for maximum power a mixture ratio of about 12.3 is required, which corresponds to an effective volatility of about 65 per cent in a feed ratio of 8:1.

These considerations lead to the conclusion that the 65 per cent point on the A. S. T. M. distillation may be related to the mixture temperature required to give fairly satisfactory performance with a carburetor delivering a constant air-fuel ratio of about 12:1; or practically perfect acceleration perform-

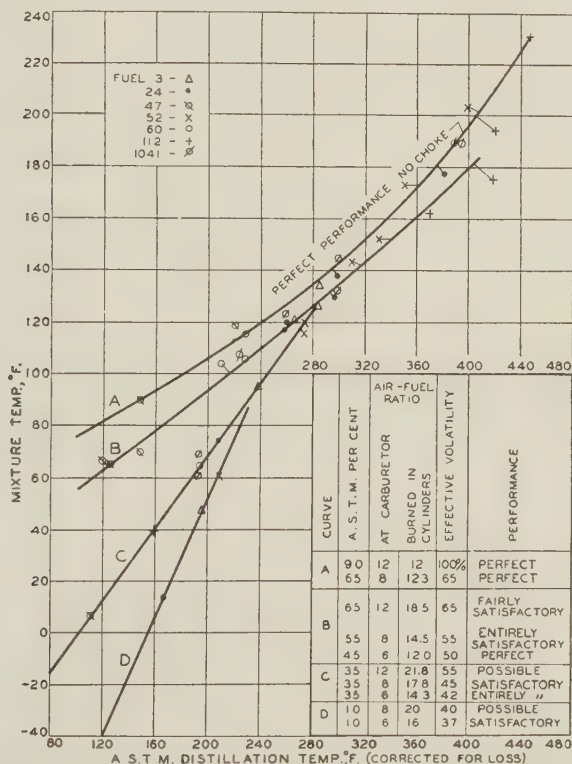


Figure 16—Relationship between A. S. T. M. Distillation Curve and Effective Volatility, Expressed as a Function of the Mixture Temperature for the Percentages Vaporized, as Shown in Table at Lower Right

ance if the carburetor is supplied with an accelerating device which enriches the mixture ratio to about 8:1 during the early stages of the acceleration, or is adjusted to deliver a rich mixture when idling. Perfect performance with a constant mixture ratio of 12:1 demands complete effective volatility as indicated by a relationship between the A. S. T. M. 90 per cent point and mixture temperature. Similarly, the 55 per cent point on the A. S. T. M. distillation should indicate the mixture temperature below which acceleration is almost impossible without use of the choke if the carburetor sup-

plies a constant fuel ratio of 12:1 and the mixture temperature giving satisfactory acceleration with carburetors equipped with adequate accelerating devices.

In Figure 16 the mixture temperature corresponding to 100 per cent effective volatility is plotted as a function of the 90 per cent A. S. T. M. point for the seven fuels studied. The points were found to lie on a smooth curve, *A*. The same curve was also found to represent the relationship between the mixture temperature for 65 per cent effective volatility in an air-fuel ratio of 8 and the 65 per cent A. S. T. M. point. Curve *B* gives the corresponding relation for 65 per cent in a 12:1 ratio and 55 per cent in an 8:1 ratio.

Although these conclusions are based entirely on the effective volatility as determined in one particular engine, the close relationship between effective and equilibrium volatility over the range of 55 to 100 per cent indicates that these conclusions should also be applicable to other motors.

If at the operating temperature the fuel does not possess sufficient effective volatility to give satisfactory acceleration performance, the driver will resort to the choke in order to obtain better throttle response. If the choke is used to enrich the mixture, or the carburetor adjusted to deliver an 8:1 air-fuel ratio under steady conditions, an effective volatility of about 45 per cent would give practically perfect throttle response on cars equipped with accelerating devices and supplying approximately a 5.4 mixture ratio during the first stages of the acceleration period, and fairly satisfactory response with cars not so equipped.

The data reported above show that 45 per cent effective volatility in these rich mixtures is indicated by about 35 per cent equilibrium volatility, or the 35 per cent point on the A. S. T. M. distillation as shown by curve *C*, Figure 16. This suggests that a low 35 per cent point on the A. S. T. M. distillation indicates entirely satisfactory performance during the warming-up period at one setting of the choke, or without use of the choke if driving at high or constant speed.

If the fuel does not possess 40 per cent effective volatility, it becomes practically impossible to drive with one choke setting unless the car is equipped with accelerating devices. Even then an effective volatility of at least 30 per cent is necessary. Apparently the 30 to 40 per cent effective volatility is related to the 10 per cent equilibrium volatility or the 10 per cent point on the A. S. T. M. distillation as indicated by curve *D*, Figure 16.

Not only is it important that the 10, 35, and 65 per cent points on the A. S. T. M. distillation be sufficiently low to allow the car to be operated in a satisfactory manner during the warming-up period and at reasonably low manifold temperatures, but if the 90 per cent point is too low and the fuel is completely vaporized at the mixture temperature existing in the manifold, loss in power and increased fuel consumption

may result if the car is equipped with accelerating devices. If the carburetor is adjusted to supply a 12:1 air-fuel ratio at all times, a fuel that is completely vaporized would give the maximum power; but if the carburetor is equipped with accelerating devices so that a mixture ratio of 8:1 is supplied during the initial periods of acceleration, and the fuel is completely effectively vaporized, a mixture ratio of 8:1 will be supplied to the cylinders during the accelerating period when a mixture of 12:1 is required. This excessively rich mixture causes a loss in power and acceleration. Although frequently observed in road tests (5), this fact has been generally overlooked in discussions of motor-fuel quality as related to the modern automobile.

It remains for these relationships to be tested on other types of engines and manifolds, and the indicated mixture temperature to be related to atmospheric temperature and duration of the warming-up period. When this information is available, it should be possible to estimate in an entirely satisfactory manner the distillation characteristics required to give any desired quality of engine performance.

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